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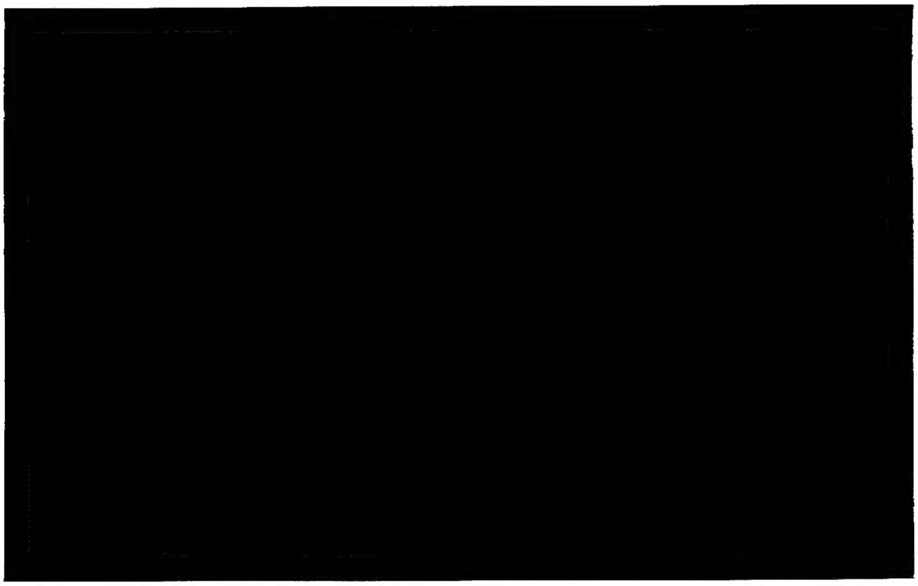

INTERDISCIPLINARY CENTER FOR APPLIED MATHEMATICS

Virginia Tech

VIRGINIA POLYTECHNIC INSTITUTE
AND STATE UNIVERSITY

Blacksburg, Virginia 24061-0531

Air Force Workshop on Optimal Design and Control

Final Technical Report on AFOSR Grant F49620-97-1-0264

for the period 1 April 1997 - 31 December 1997

by
John A. Burns
Eugene M. Cliff

Center for Optimal Design And Control
Interdisciplinary Center for Applied Mathematics
Virginia Polytechnic Institute and State University

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Interdisciplinary Center for Applied Mathematics
Wright House, West Campus Drive
Virginia Polytechnic Institute and State University
Blacksburg, Virginia 24061-0531

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This report contains a summary and highlights of the work funded by the Air Force under AFOSR Grant F49620-97-1-0264, titled " Air Force Workshop on Optimal Design and Control ". This effort was conducted by the Air Force Center for Optimal Design and Control (**CODAC**), during the period 1 April 1997 - 31 December 1997. The Center planned, organized and ran a workshop in Washington, DC from 30 September through 3 October 1997. The workshop was attended by sixty-six participants with thirty-six technical presentations.

The objectives of the workshop included an assessment of current research efforts in optimal design, an evaluation of Air Force needs and identification of future directions in optimal design.. The speakers, including twenty invited leading researchers, covered a variety of topics including: Sensitivity Equation Methods, Adjoint Methods, Automatic Differentiation, Optimization Theory and Algorithms and Engineering Design Applications. Twenty-two of the technical papers have been assembled into a Proceeding volume, to be published by Birkhauser-Boston. A second volume assessing the state-of-the-art and future directions will also be published by Birkhauser-Boston

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Summary

This Grant provided partial support for a workshop on Computational Methods for Optimal Design and Control that was held in Washington, DC, 30 September – 3 October 1997. The basic objectives of the proposed workshop were

1. to assess the current status of research in optimal design as it applies to Air Force problems,

2. to bring together the diverse group of researchers in this area in order to share and compare the different approaches to inverse design and

3. to provide an evaluation of Air Force needs and future directions in computational tools for optimal design.

To meet these objectives approximately twenty internationally recognized leaders were invited to present status reports on their basic research programs. With the addition of contributed talks a total of thirty-six presentations were made. In addition, each attendee was asked to provide a brief hand-written summary of issues and challenges. This information was used to identify future directions and to draft a report analyzing the challenges posed by future Air Force problems. Two volumes have been produced as a result of the workshop. One volume is a proceedings containing twenty-two of the scientific papers. The second volume provides an assessment of the state of the art and an analysis of future directions in the field. Both volumes are being published by *Birhkauser - Boston*. The Proceedings volume is in-press and will appear in April 1998. The front-matter from this volume is included as an Appendix. The Future Directions volume is in editorial review and will be available later in the year.

1 Introduction and Overview

Many of the most challenging engineering design applications currently facing the Air Force and the aerospace industry may be formulated as optimal design or inverse problems. These applications include, but are not limited to, structural optimization, nozzle and shape design for wind tunnel testing, wing/body design, inverse design for improved stealth, general shape optimization for flow management, combustion and high speed flows. It is this universal range of applications that has generated a demand for new optimization-based computational tools. The widespread demand for such tools has generated a tremendous surge in research on computational methods for optimal design. During the past decade, this work has produced numerous new methods and lead to the development of a wide variety of computational algorithms.

In order to address these fundamental questions, the workshop brought together sixty-three participants from a wide spectrum of research disciplines including: optimization theory, control theory, computational mechanics, structural dynamics, computer science, computational fluid dynamics, numerical analysis and computational physics.

The Conference Program is included as Appendix A and a list of participants is included as Appendix B. The front-matter of the Proceedings volume, to be published by *Birhkauser - Boston*, is included as a final Appendix.

2 Technical Areas

The thirty-six presentations at the Workshop covered a variety of themes including:

- Sensitivity Equation Methods
- Adjoint Methods
- Automatic Differentiation
- Optimization Theory and Algorithms
- Engineering Design Applications

2.1 Sensitivity Equation Methods

There are a variety of approaches to the formulation and solution of engineering design problems. We concentrate here on a class of problems which can be formulated as mathematical optimization problems. When used as a paradigm for engineering design, the state sensitivities (derivative of the state with respect to the design parameters) play two key roles. They provide gradient information for the optimization algorithm and sensitivity information for analysis of a particular design. Therefore, efficient computation of accurate sensitivities is a major requirement of any design tool.

2.2 Adjoint Methods

For many applications the adjoint equation approach is an attractive alternative to the SEM for the computation of gradients. While the adjoint equations are used for various distributed optimal control problems, many issues are still subject to active research. One issue that arises repeatedly is the issue of consistency and adjointness: In many applications, discretizations of the infinite dimensional adjoint equation are not the adjoint equations of the discretized problem and vice versa. Additional research issues arise that concern the correct mathematical setting of the problem, formulation of the adjoint equation, in particular boundary conditions for the adjoint, and the existence of the adjoints.

2.3 Automatic Differentiation

In many applications the direct or analysis problem results in software package capable of predicting the system's performance for given values of the design parameters. In such setting it is natural to adopt a computational viewpoint that focuses on exploiting the existing simulation code. Thus the basic idea in automatic differentiation is to produce an auxiliary computer code that will compute the sensitivity of the original code to changes in data. The idea is very attractive in many industrial applications wherein complex *legacy codes* have been developed for the direct problem. OSR has previously sponsored a workshop in this area in January 1991.

2.4 Optimization Theory and Algorithms

Design problems can be formulated as optimization problems in a variety of ways, among these the black–box–formulation and the all–at–once formulation are extreme points. In many cases the smoothness (or lack thereof) of the cost and constraint functionals is a key issue. For smooth problems sequential quadratic programming (SQP) methods with trust–region strategies are among the preferred approaches. However, many *legacy* codes for simulating the behavior of engineering systems include features which induce non-smooth dependence on design parameters. Thus, a number of contributors addressed such issues. Finally, in many engineering disciplines one has a spectrum of available analysis models/tools. These may range from simple inexpensive database-interpolation methods, to sophisticated CFD simulation codes. Several speakers addressed issues related to model-management in the context of optimization.

2.5 Engineering Design Applications

The motivation for the tool-development described above stems from a variety of applications in aerospace design. One aspect of these problems is their multidisciplinary nature. In a comprehensive design for transport aircraft, for example, structural, aerodynamic, propulsive and flight-control requirements must each be considered. Several speakers addressed these concepts.

Workshop Program

Tuesday Morning, 30 September 1997

08:00 - 08:45	Registration
08:45 - 09:00	Welcome: Salon A
	Session TU-AM: Salon A **Session Chair: Major Scott Schreck**
09:00 - 09:45	Roland Glowinski University of Houston *Some Fundamental Issues in Optimal Design/Shape Optimization*
09:45 - 10:30	Ekkehard Sachs Universitat Trier *New Numerical Methods in Optimal Control*
10:30 - 11:00	Coffee Break: Salon A
11:00 - 11:45	Max Gunzburger Iowa State University *Sensitivities and Adjoints in Computational Methods for Optimal Flow Control*

Tuesday Afternoon, 30 September 1997

	Session TU-PM: Salon A **Session Chair: Eugene M. Cliff**
13:15 - 14:00	Andrew Conn T.J. Watson Research Center, IBM *Recent Progress in Unconstrained Nonlinear Optimization Without Derivatives*
14:00 - 14:45	Thomas Coleman Cornell University *Automatic Differentiation is NOT Automatic (When Applied to Inverse Problems in Optimal Design)*
14:45 - 15:15	Coffee Break: Salon A
15:15 - 16:00	Gal Berkooz BEAM Technologies, Inc *Optimization in Real World Engineering Design: Needs and Opportunities*
16:00 - 16:45	Jason Speyer University of California, Los Angeles *Robust Reduced-Order Controller of Transitional Boundary Layers*
16:45 - 17:15	Discussion

Wednesday Morning, 1 October 1997

	Session WE-AM-1: Salon B **Session Chair: John A. Burns**
08:00 - 08:45	Jaroslav Haslinger Charles University *Fictitious Domain Approaches and* *Global Optimization Methods in Shape Optimization*
08:45 - 09:30	Nicholas Zabaras Cornell University *Sensitivity Analyses and Adjoint Method Algorithms* *for the Design of Material Processes*
09:30 - 10:00	Coffee Break: Salon A
	Session WE-AM-2: Salon B **Session Chair: Belinda King**
10:00 - 10:30	Eyal Arian ICASE *MDO-A Mathematical View Point*
10:30 - 11:00	Matthias Heinkenschloss Rice University *Interior point SQP Methods for* *Distributed Control Problems*
11:00 - 11:30	Josip Loncaric ICASE *Sensor/Actuator Placement Via Optimal* *Distributed Control of Exterior Stokes Flow*
11:30 - 12:00	Arun Verma Cornell University *Automatic Differentiation and* *MATLAB Interface Toolbox (ADMIT)*

Wednesday Afternoon, 1 October 1997

	Session WE-PM: Salon B **Session Chair: John Dennis**
13:30 - 14:15	Allen Tannenbaum University of Minnesota *Visual Information in a Feedback Loop: A Control/Computer Vision Synthesis*
14:15 - 15:00	Eugene Cliff Virginia Polytechnic Institute and State University *An Overview of Research at the Center for Optimal Design And Control*
15:00 - 15:30	Coffee Break: Salon A
15:30 - 16:15	Jean-Paul Zolesio Institut Non Lineare de Nice *Shape Differential Equations*
16:15 - 16:45	Discussion

Thursday Morning, 2 October 1997

	Session TH-AM: Salon B **Session Chair: Terry Herdman**
08:00 - 08:45	John Dennis Rice University *Optimization Using Surrogate Objectives*
08:45 - 09:30	Anthony Patera Massachussetts Institute of Technology *Fast Bounds for Partial Differential Equation Outputs*
09:30 - 10 :00	Coffee Break: Salon A
10:00 - 10:45	Andrew Godfrey AeroSoft, Inc. *Using Sensitivities for Flow Analysis*
10:45 - 11:30	Karl Kunisch KFU Graz *Numerical Optimal Control for Navier Equations*

Thursday Afternoon, 2 October 1997

	Session TH-PM 1: Salon B **Session Chair: Bernard Grossman**
13:15 - 13:45	Robert Lewis NASA Langley Research Center *Sensitivity Calculations and the Adjoint Equations from a Nonlinear Programming Perspective*
13:45 - 14:15	Ajit Shenoy Virginia Polytechnic Institute and State University *An All-At-Once Approach to Airfoil Design*
14:15 - 14:45	Dominique Pelletier Ecole Polytechnique de Montreal *On Computational Issues in Using Adaptive FEM and the Sensitivity Equation Method*
14:45 - 15:15	Coffee Break: Salon A
	Session TH-PM 2: Salon B **Session Chair: Marc Jacobs**
15:15 - 15:45	Jeff Borggaard Cornell University *On Optimal Design in Forced Convection*
15:45 - 16:15	John Otto Massachussetts Institute of Technology *A Surrogate-Pareto Approach to Shape Optimization: Level-Set Based Geometry Description*
16:15 - 16:45	Belinda King Oregon State University *An Optimal Design Approach to the Construction of Practical Feedback Controllers*
16:45 - 17:15	Duane Knill Virginia Polytechnic Institute and State University *Efficient Implementation of Euler Solutions for Supersonic Aerodynamic Predictions in Multidisciplinary HSCT Design*

Friday Morning, 3 October 1997

	Session FR-AM-1: Salon B **Session Chair: Max Gunzburger**
08:00 - 08:45	C.T. Kelley North Carolina State University *The Simplex Gradient and* *Noisy Optimization Problems*
08:45 - 09:30	Bernard Grossman Virginia Polytechnic Institute and State University *Multidisciplinary Design Optimization* *of Advanced Aircraft*
09:30 - 10:00	Coffee Break: Salon A
	Session FR-AM-2: Salon B **Session Chair: Ekkehard Sachs**
10:00 - 10:30	Martin Berggren FFA, The Aeronautical Research Institute of Sweden *Optimal Disturbances in Boundary Layers*
10:30 - 11:00	Dawn Stewart Virginia Polytechnic Institute and State University *Projection Methods for Accurate Computation* *of Design Sensitivities*
11:00 - 11:30	Paul Hovland Argonne National Laboratory *Automatic Differentiation* *and Navier-Stokes Computations*
11:30 - 12:00	Jean-Francois Hétu National Research Council of Canada *Optimization of Industrial Forming Processes:* *Issues and Challenges*

Friday Afternoon, 3 October 1997

	Session FR-PM: Salon B **Session Chair: Nicholas Zabaras**
13:30 - 14:15	Ilan Kroo Stanford University *Optimal Design of Aerospace Systems–* *Architectures and Applications*
14:15 - 15:00	Antony Jameson Stanford University *Optimum Design of Airplane Wings* *in Transonic Viscous Flow*
15:00 - 15:30	Coffee Break: Salon A
16:00 - 16:45	H.T. Banks North Carolina State University *Identification Problems in Electro-Magnetics*
16:45 - 17:15	Closing Session: Dr. John Burns

List of Participants

Workshop on Optimal Design and Control
Crystal Gateway Marriott
September 30 - October 3, 1997

Arian, Eyal
ICASE
Mail Stop 403
6 North Dryden Street
NASA Langley Research Center
Hampton, VA 23681-0001
757-864-2208
arian@icase.edu

Banks, H.T.
North Carolina State University
324 Harrelson Hall
CRSC, Box 82
Raleigh, NC 27695
919-515-3968
htbanks@crsc1.math.ncsu.edu

Berggren, Martin
FFA, The Aeronautical Research
Institute of Sweden
Computational Aerodynamics
Department
P.O. Box 11021
S-161 11 Bromma, Sweden
46-8-6341071
bnm@ffa.se

Berkooz, Gal
BEAM Technologies, Inc.
110 North Cayuga Street
Ithaca, NY 14850
607-273-4367
gb@beamtech.com

Boggs , Paul
National Institute of Standards
Mathematical and Computational
Sciences Division
Gaithersburg, MD 208999
301-975-3816
boggs@nist.gov

Borggaard, Jeffrey
Cornell University
287 Upson Hall
Mechanical and Aerospace
Engineering
Ithaca, NY 14853
607-255-8270
borggajt@fred.mae.cornell.edu

Bradley, Beth
University of Louisville
Department of Mathematics
Louisville, KY 40292
502-852-6826
mebrad01@homer.louisville.edu

Burns, John
Virginia Polytechnic Institute and
State University
Interdisciplinary Center for
Applied Mathematics
Blacksburg, VA 24061-0531
540-231-7667
burns@icam.vt.edu

Camphouse, Chris
Virginia Polytechnic Institute and
State University
Interdisciplinary Center for
Applied Mathematics
Blacksburg, VA 24061-0531
540-231-7667
rcamphou@math.vt.edu

Cifuentes, Paula
Virginia Polytechnic Institute and
State University
Northern Virginia Graduate Center
7054 Haycock Road
Falls Church, VA 22043-2311
703-538-8395
pcifuent@sun.icam.vt.edu

Cliff, Eugene
Virginia Polytechnic Institute and
State University
Interdisciplinary Center for
Applied Mathematics
Blacksburg, VA 24061-0531
540-231-7667
cliff@icam.vt.edu

Coleman, Thomas
Cornell University
Dept. of Computer Science
725 Eng. and Theory Center Bldg
Ithaca, NY 14853-3801
607-255-9203
coleman@cs.cornell.edu

Conn, Andrew
T.J. Watson Research Center, IBM
P.O. Box 218
Yorktown Heights, NY 10598-0218
914-945-1589
arconn@watson.ibm.com

Dennis, John
Rice University
CAAM-MS 134
6100 Main Street
Houston, TX 77005
713-527-4094713-527-4094
dennis@rice.edu

Feijoo, Gonzalo R.
Stanford University
Department of Mechanical Engineering
Division of Mechanics and Computation
Durand Building Room 262
Stanford, CA 94305
650-723-1142
grfeij@leland.stanford.edu

Gao, Dong-Ming
National Research Council Canada
75 de Mortagne Blvd.
Boucherville
Quebec, Canada
514-641-5030
dong-ming.gao@mkc.ca

Giesy, Daniel P.
NASA Langley Research Center
Guidance and Control Branch
MS 161
Hampton, VA 23681
757-864-4006
d.p.giesy@larc.nasa.gov

Gilmore, Paul
Tektronix, Inc.
Color Printing and Imaging Division
26600 S.W. Parkway
P.O. Box 1000, M/S 63-424
Wilsonville, OR 97070
503-685-2288
paulgi@pogo.wv.tek.com

Glowinski, Roland
University of Houston
Department of Mathematics
4800 Calhoun Road
Houston, TX 77204-3476
713-743-3473
roland@math.uh.edu

Godfrey, Andrew
AeroSoft, Inc.
1872 Pratt Drive
Suite 1275
Blacksburg, VA 24060
540-231-8117
godfrey@aerosft.com

Grossman, Bernard
Virginia Polytechnic Institute and State University
Department of Aerospace and Ocean Engineering
Blacksburg, VA 24061-0203
540-231-6611
grossman@apollo.aoe.vt.edu

Gunzburger, Max
Iowa State University
Department of Mathematics
400 Carver Hall
Ames, IA 50011-2064
515-294-1752
gunzburg@iastate.edu

Haslinger, Jaroslav
Charles University
Faculty of Mathematics and Physics
KFK MFF UK
Ke Karlovu 5
121 16 Prague 2, CZECH REPUBLIC
420-2-21911312
haslin@apollo.karlov.mff.cuni.cz

Heinkenschloss, Matthias
Rice University
Department of Computational and Applied Mathematics
6100 Main Street
Houston, TX 77005-1892
713-285-5176
heinken@caam.rice.edu

Henningson, Dan
FFA Aeronautical Research Institute of Sweden
Box 11021
S-16111 Bromma, Sweden
46-8-6341270
hnd@ffa.se

Herdman, Terry
Virginia Polytechnic Institute and State University
Interdisciplinary Center for Applied Mathematics
Blacksburg, VA 24061-0531
540-231-7667
herdman@icam.vt.edu

Herling, William
Boeing Defense and Space Group
Aerodynamics Technology
P.O. Box 3707
M.S.4A-38
Seattle, WA 98124-2207
206-662-0056
wwh3507@hef.ds.boeing.com

Hetu, Jean-Francois
National Research Council of Canada
Industrial Materials Institute
75 de Mortagne
Boucherville,Quebec
Canada J4B 6Y4
phone:
514-641-5364
jean-francois.hetu@nrc.ca

Holland, Charles
Air Force Office of Scientific Research
110 Duncan Avenue
Suite B115
Bolling AFB, 20332-0001
holland@afosr.af.mil

Hovland, Paul
Argonne National Laboratory
Mathematics and Computer Science Division
Building 221
9700 S. Cass Avenue
Argonne, IL 60439
630-252-6384
hovland@mcs.anl.gov

Hulsing, Kevin
Virginia Polytechnic Institute and State University
Interdisciplinary Center for Applied Mathematics
Blacksburg, VA 24061-0531
540-231-7667
hulsing@icam.vt.edu

Jacobs, Marc
Air Force Office of Scientific Research
110 Duncan Avenue
Suite B115
Bolling AFB, 20332-0001
marc@stealth.afosr.af.mil

Jameson, Antony
Stanford University
Department of Aeronautics and Astronautics
Durand 279
Stanford, CA 94305
415-725-6208
jameson@gorilla.stanford.edu

Kearsley, Anthony
NIST
Math and Computer Science Division
Gaithersburg, MD 20899-0001
301-975-6103
ajk@cam.nist.gov

Kelley, Carl T.
North Carolina State University
Department of Mathematics
Box 8205
Raleigh, NC 27695-8205
919-515-7163
tim_kelley@ncsu.edu

King, Belinda
Oregon State University
Department of Mathematics
Corvallis, OR 97331
541-737-4686
bbking@math.orst.edu

Knill, Duane
Virginia Polytechnic Institute and State University
215 Randolph Hall
Aerospace and Ocean Engineering
Blacksburg, VA 24061-0203
540-231-3550
knill@aoe.vt.edu

Kroo, Ilan
Stanford University
Department of Aeronautics and Astronautics
Standford, CA 94305-4035
415-723-2994
kroo@leland.stanford.edu

Kunisch, Karl
University of Graz
Institute fuer Mathematik
Heinrichstrasse 36
A 8010 Graz, Austria
0043-316-380-5162
kunisch@kfunigraz.ac.at

Lewis, Robert
ICASE
Mail Stop 403
NASA Langley Research Center
Hampton, VA 23681-0001
757-864-2190
buckaroo@icase.edu

Limache, Alejandro
Virginia Polytechnic Institute and State University
Interdisciplinary Center for Applied Mathematics
Blacksburg, VA 24061-0531
540-231-7667
alimach@icam.vt.edu

Loncaric, Josip
ICASE
Mail Stop 403
NASA Langley Research Center
Hampton, VA 23681-0001
757-864-2192
josip@icase.edu

Maghami, Peiman G.
NASA Langley Research Center
Mail Stop 161
Hampton, VA 23681-0001
757-864-4039
p.g.maghami@larc.nasa.gov

Malhotra, Manish
Stanford University
PO Box 7169
Stanford, CA 94309
650-723-8595650-723-8595
maam-sun2.stanford.edu

Moerder, Dan
NASA Langley Research Center
Mail Stop 161
Hampton, VA 23681
757-864-6495
dmoerder@lambic.larc.nasa.gov

Nash, Stephen
George Mason University
Operations Research Dept
Fairfax, VA 22030
703-993-1678
snash@gmu.edu

Otto, John C.
M.I.T.
Department of Aeronautics and Astronautics
Fluids Lab Room 3-243
77 Massachusettes Avenue
Cambridge, MA 02139
617-253-0229
jo@andrei.mit.edu

Patera, Anthony
M.I.T.
Department of Mechanical Engineering
Room 3-264
77 Massachusetts Avenue
Cambridge, MA 02139
617-253-8122
patera@mit.edu

Pelletier, Dominique
Ecole Polytechnique de Montreal
PO Box 6079
Station A
Montreal, Canada H3C 3A7
514-340-4711, ext. 4102
dp@galerkin.meca.polymtl.ca

Roetman, Fritz
Boeing Defense and Space Group
Aerodynamics Technology
P.O. Box 3707
MS 4A-38
Seattle, WA 98124-2207
206-662-0063
ernest.l.roetman@boeing.com

Rubio, Diana
North Carolina State University
Center for Research in Scientific Computation
Box 8205
Raleigh, NC 27695
919-515-3310
adrubio@eos.ncsu.edu

Sachs, Ekkehard
Universität Trier
FB IV-Mathematik
54296 Trier, Germany
49-651-201-3474
sachs@uni-trier.de

Schreck, Scott
Air Force Office of Scientific Research/NM
110 Duncan Avenue
Suite B115
Bolling AFB, DC 20332-8050
202-767-7902
scott.schreck@afosr.af.mil

Shenoy, Ajit
Virginia Polytechnic Institute and State University
Interdisciplinary Center for Applied Mathematics
Blacksburg, VA 24061-0531
540-231-7667
shenoy@icam.vt.edu

Speyer, Jason
University of California, Los Angeles
Mechanical and Aerospace Engineering Department
Box 951597
Los Angeles, CA 90095-1597
310-206-4451
speyer@seas.ucla.edu

Stanley, Lisa
Virginia Polytechnic Institute and State University
Interdisciplinary Center for Applied Mathematics
Blacksburg, VA 24061-0531
540-231-7667
stanley@math.vt.edu

Starnes, Craig
Booz, Allen & Hamilton, Inc.
2231 Crystal Drive
Arlington, VA 22202
703-902-4026
starnes-craig@bah.com

Stewart, Dawn
Virginia Polytechnic Institute and State University
Interdisciplinary Center for Applied Mathematics
Blacksburg, VA 24061-0531
540-231-7667
stewartd@icam.vt.edu

Tannenbaum, Allen
University of Minnesota
200 Union Street S.E.
Department of Electrical Engineering
Minneapolis, MN 55455
612-625-6395612-625-6395
tannenba@ee.umn.edu

Torczon, Virginia
College of William and Mary
Dept. of Computer Science
P.O. Box 8795
Williamsburg, VA 23187-8795
757-221-3460
va@cs.wm.edu

Verma, Arun
Cornell University
716 Rhodes Hall
Ithaca, NY 14853
phone:
607-254-8807
verma@cs.cornell.edu

Zabaras, Nicholas
Cornell University
Sibley School of Mechanical and
Aerospace Engineering
188 Rhodes Hall
Ithaca, NY 14853-3801
607-255-9104
njz1@cornell.edu

Zolésio, Jean-Paul
Institut Non Lineaire de Nice
2004 Route des Lucioles
BP 93 06902 Sohpia Antipolis
Cedex, France
336-09-57-88-94
jean.paul.esio@inria.sophia.fr

Proceedings Volume – Frontmatter

COMPUTATIONAL METHODS FOR OPTIMAL DESIGN AND CONTROL

Proceedings of the AFOSR Workshop on Optimal Design and Control
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30 September–3 October, 1997

Jeff Borggaard, John Burns,
Eugene Cliff and Scott Schreck
Editors

Jeff Borggaard
Center for Optimal Design and Control
Sibley School of Mechanical and Aerospace Engineering
Cornell University
Ithaca, NY 14853, USA
jborggaard@na-net.ornl.gov

John Burns
Center for Optimal Design and Control
Interdisciplinary Center for Applied Mathematics
Virginia Tech
Blacksburg, VA 24061-0531, USA
burns@icam.vt.edu

Eugene Cliff
Center for Optimal Design and Control
Interdisciplinary Center for Applied Mathematics
Virginia Tech
Blacksburg, VA 24061-0531, USA
cliff@icam.vt.edu

Scott Schreck
Air Force Office of Scientific Research
Bolling Air Force Base
Washington, DC 20332-8050, USA
scott.schreck@afosr.af.mil

CONTENTS

PREFACE

This volume contains the proceedings of the Second International Workshop on Optimal Design and Control, held in Arlington, Virginia, 30 September–3 October, 1997. The First Workshop was held in Blacksburg, Virginia in 1994. The proceedings of that meeting also appeared in the Birkhauser series on Progress in Systems and Control Theory and may be obtained through Birkhauser.

These workshops were sponsored by the Air Force Office of Scientific Research through the Center for Optimal Design and Control (CODAC) at Virginia Tech. The meetings provided a forum for the exchange of new ideas and were designed to bring together diverse viewpoints and to highlight new applications. The primary goal of the workshops was to assess the current status of research and to analyze future directions in optimization based design and control. The present volume contains the technical papers presented at the Second Workshop. More than 65 participants from 6 countries attended the meeting and contributed to its success.

It has long been recognized that many modern optimal design problems are best viewed as variational and optimal control problems. Indeed, the famous problem of determining the body of revolution that produces a minimum drag nose shape in hypersonic flow was first proposed by Newton in 1686. Optimal control approaches to design can provide theoretical and computational insight into these problems. This volume contains a number of papers which deal with computational aspects of optimal control.

The workshop was a gathering of engineers and mathematicians actively involved in innovative research in control and optimization, with an emphasis placed on optimal design problems governed by partial differential equations. Many difficulties arise when trying to implement approximation techniques for these problems. These difficulties range from computational issues, such as the accuracy, ease and efficiency of state/function and gradient calculations, to concerns about integrating calculations from several subdisciplines. For example, contributions concerning gradient calculations can be loosely broken into three categories: (i) Automatic Differentiation, (ii) Adjoint Methods and (iii) Sensitivity Equations Methods.

In many cases, a detailed solution of the full physics-based state equations (partial differential equations or large systems of ordinary differential equations) is expensive. However, reduced order models with varying levels of validity can often be used to develop optimal design strategies. Several articles describe techniques for managing models in optimization algorithms. Model management is also considered for the case where different disciplines must be integrated. Model uncertainty caused by coarse approximations of partial differential equations or by obtaining function evaluations through experiment can introduce unacceptable noise in the design objective function. Convergence of optimization algorithms for problems with model uncertainty is discussed by various contributors.

Many important optimal design applications can be formulated as shape optimization problems. Shape optimization leads to additional difficulties and often requires the development of special techniques to address complex theoretical and computational issues. These difficulties range from theoretical considerations involving the development of proper mathematical framework for the discussion of shape derivatives, to computational methods for efficient calculation, or elimination of mesh gradients. Sensitivity equation methods and fictitious domain approaches to these problems are found in various articles on shape optimization.

The diverse background and experience of the participants, ranging from academia, to industry,to government laboratories, lead to a variety of techniques to address these difficulties. Overall, it is clear that there has been significant progress in the development of new computational and mathematical tools for optimal design and control. Moreover, these tools are being applied to very complex systems and have important applications to aerodynamic design, fluid flows, materials processing, inverse design and feedback control. On the other hand, there are many theoretical and practical issues that have not been resolved, and when resolved, could lead to revolutionary advances in design and control methodology. During the workshop the participants submitted position papers that identified these issues and suggested future research directions to address these difficult problems. The conclusions based on these suggestions will appear in a follow-up volume.

Finally, we would like to acknowledge the efforts of the Organizing Committee, the graduate students at Virginia Tech and the staff at ICAM. In particular, special thanks goes to Dr. Bernard Grossman, Melissa Chase and Sydney Crowder for their help in putting together the interesting and informative workshop that led to these proceedings. We also gratefully acknowledge the support of the Air Force Office of Scientific Research for funding the workshop under AFOSR grants F49620-97-1-0264 and F49620-96-1-0329.

Jeff Borggaard, John Burns,
Eugene Cliff and Scott Schreck
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CONTRIBUTORS

Paul Andersson – FFA, the Aeronautical Research Institute Sweden, Computational Aerodynamics Department, P.O Box 11021, S-161 11 Bromma, Sweden.

Eyal Arian – Institute for Computer Applications in Science and Engineering, Mail Stop 403, NASA Langley Research Center, Hampton, VA 23681.

Martin Berggren – FFA, the Aeronautical Research Institute Sweden, Computational Aerodynamics Department, P.O Box 11021, S-161 11 Bromma, Sweden.

Christian Bischof – Mathematics and Computer Science Division, Argonne National Laboratory, 9700 S. Cass Avenue, Argonne, IL 60439-4844.

Andrew Booker – Mathematics & Engineering Analysis, Boeing Information Support Services.

Jeff Borggaard – Sibley School of Mechanical and Aerospace Engineering, Upson Hall, Cornell University, Ithaca, NY 14853.

David Bortz – North Carolina State University, Department of Mathematics, Center for Research in Scientific Computation, Box 8205, Raleigh, NC 27695-8205.

Eugene Cliff – Center for Optimal Design and Control, Interdisciplinary Center for Applied Mathematics, Virginia Tech, West Campus Drive, Blacksburg, VA 24061-0531.

Thomas Coleman – Computer Science Department and Center for Applied Mathematics, Cornell University, Ithaca, NY 14850.

Luca Cortelezzi – Department of Mechanical and Aerospace Engineering and Department of Mathematics, University of California, Los Angeles, CA 90095.

John Dennis, Jr. – Department of Computational and Applied Mathematics, Center for Research on Parallel Computation, Rice University, Houston, TX.

M. Fahl – FB IV - Mathematik, Universität Trier, 54286 Trier, Germany.

Paul Frank – Mathematics & Engineering Analysis *Boeing Information Support Services.*

Roland Glowinski – University of Houston, Department of Mathematics, Houston, TX 77204-3476.

Andrew Godfrey – Aerosoft, Inc., 1872 Pratt Drive, Ste. 1275, Blacksburg, VA 24060.

Max Gunzburger – Department of Mathematics, Iowa State University, Ames, IA 50011-2064.

Jaroslav Haslinger – Charles University, Prague.

Jiwen He – University of Houston, Department of Mathematics, Houston, TX 77204-3476.

Matthias Heinkenschloss – Department of Computational and Applied Mathematics, Rice University, Houston, TX.

Dan Henningson – FFA, the Aeronautical Research Institute Sweden, Computational Aerodynamics Department, P.O Box 11021, S-161 11 Bromma, Sweden.

Jean-François Hétu – Industrial Materials Institute, National Research Council Canada, 75, de Mortagne, Boucherville, QC, Canada J4B 6Y4.

Paul Hovland – Mathematics and Computer Science Division, Argonne National Laboratory, 9700 S. Cass Avenue, Argonne, IL 60439-4844.

Florin Ilinca – Industrial Materials Institute, National Research Council Canada, 75, de Mortagne, Boucherville, QC, Canada J4B 6Y4.

C. Tim Kelley – North Carolina State University, Department of Mathematics, Center for Research in Scientific Computation, Box 8205, Raleigh, NC 27695-8205.

Robert Michael Lewis – Institute for Computer Applications in Science and Engineering, Mail Stop 403, NASA Langley Research Center, Hampton, VA 23681-0001.

Josip Lončarić – Institute for Computer Applications in Science and Engineering, Mail Stop 403, NASA Langley Research Center, Hampton, VA 23681-0001.

Yvon Maday – Laboratoire d'Analyse Numérique, Université Pierre and Marie Curie (Paris VI).

Bijan Mohammadi – University of Montpellier II and INRIA, Math. Dept, CC51, 34095 Montpellier Cedex 5, France.

Marius Paraschivoiu – Department of Mechanical Engineering, Massachusetts Institute of Technology, 77 Massachusetts Avenue, Cambridge, MA 02139.

Anthony Patera – Department of Mechanical Engineering, Massachusetts Institute of Technology, 77 Massachusetts Avenue, Cambridge, MA 02139.

Dominique Pelletier – Department of Mechanical Engineering, Ecole Polytechnic de Montréal, C.P. 6079, Succ. A, Montréal, QC, Canada H3C 3A7.

Jaime Peraire – Department of Aeronautics and Astronautics, Massachusetts Institute of Technology, 77 Massachusetts Avenue, Cambridge, MA 02139.

Ekkehard Sachs – FB IV - Mathematik, Universität Trier, 54286 Trier, Germany.

Fadil Santosa – School of Mathematics, University of Minnesota, Minneapolis, MN 55455.

David Serafini – Department of Computational and Applied Mathematics, Center for Research on Parallel Computation, Rice University, Houston, TX.

Ajit Shenoy – Department of Mathematics, Iowa State University, Ames, IA 50011-2064.

Jason Speyer – Department of Mechanical and Aerospace Engineering, University of California, Los Angeles, CA 90095.

Lisa Stanley – Center for Optimal Design and Control, Interdisciplinary Center for Applied Mathematics, Virginia Tech, Blacksburg, VA 24061-0531.

Dawn Stewart – Center for Optimal Design and Control, Interdisciplinary Center for Applied Mathematics, Virginia Tech, Blacksburg, VA 24061-0531.

Allen Tannenbaum – Department of Electrical Engineering, University of Minnesota, Minneapolis, MN 55455.

Virginia Torczon – Computer Science Department, College of William & Mary, Williamsburg, VA

Arun Verma – Computer Science Department, Cornell University, Ithaca, NY 14850.

Anthony Yezzi, Jr. – Department of Electrical Engineering, University of Minnesota, Minneapolis, MN 55455.

Nicholas Zabaras – Sibley School of Mechanical and Aerospace Engineering, 188 Frank H. T. Rhodes Hall, Cornell University, Ithaca, NY 14853-3801.

Jean-Paul Zolésio – Institut Non Linéaire de Nice, CNRS, 1361 Route des Lucioles, 06904 Sophia Antipolis Cédex, France.